

DUMBO: A PACHYDERMAL ROCKET MOTOR

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Since ROVER/NERVA technology has been ably covered by other speakers, and since the intention of this workshop was to cast a rather wide net, I thought it might be useful to tell you a little bit about a lesser known chapter of nuclear rocket history for a couple of reasons. First, perhaps we might learn something from that history, and second, under certain circumstances it might provide an alternative that would be useful in helping to develop a higher performance nuclear rocket engine.

Dumbo goes back to the very beginning of nuclear rocket technology. The first report on Dumbo, from which I have stolen this title, was written by B.B. McIntyre, R.M. Potter and E.S. Robinson in 1955. In 1957, a somewhat larger report was issued, with roughly the same authors.

My first point is that really there are only very few basic concepts in almost any field, in particular in nuclear rocketry, and we come back to the same things over and over. I think it is worthwhile taking into account the lesson from that, that sometimes it pays us to take a different way of looking at the world. Even though ideas are not new, maybe we can learn something from looking at them in a little bit different way.

Dumbo, like several of the reactors you have already heard about, is what I call a folded flow reactor (Figure 1). While it's not my term, it's one that I like to use because it describes very well the idea that the propellant comes in axially and leaves axially, but during some part of its passage through the reactor it flows in a radial direction.

Figure 1 is one of the very early Dumbo pictures. You may not be able to tell from the figure but this particular design had the cold gas flowing inside the cylindrical fuel sections and flowing radially outward through the fuel and then exiting through the annuli around the various cylinders.

Figure 2 is a typical picture; you have seen similar ones earlier today for related concepts. The reflector is a little bit unsophisticated, being flat plates of beryllium, but in any case, we are going to use one of the series of hexagonal magic numbers of fuel cylinders, 1, 7, 19, 37, 61, 91, etc. in almost any reactor that we put together. This is similar. The hexagons are zirconium hydride and the little double circles in the centers depict an annulus of fuel.

Figure 3 is a similar picture showing the full system with some detailing of the reactor components. The Dumbo system started out with very, very thin fuel elements. In fact, there was talk of using 3 mil corrugated foils, made in the shape of a washer, that were going to be stacked together to form the fuel elements, with flow to be metered by the

size of the corrugations between the fuel. People learned fairly quickly that you can't make something like that very well or very repeatably. As a consequence, during the program the fuel elements grew to be a lot coarser as the design progressed.

Figure 4 shows a fuel geometry that we were looking at fairly closely at the end of the program. Each fuel washer would be a few tens of mils thick, separated by what we called the spider made of an unloaded material. For the first planned reactor experiment, the fuel material for Dumbo was to be the more easily fabricated Molybdenum UO_2 cermet, with the premise that later we would be able to use tungsten UO_2 fuel, and have similar geometry advantages with higher temperature materials. Others today have pointed out the advantages of radial flow reactors as compared to axial flow reactors.

The key characteristics of the system (Figure 5) are some that I have mentioned earlier; folded flow, use of fuel washers, large flow area, large surface area, small fuel volume, hydride moderator, and cermet fuel. I am going to be talking to you a little bit later about adapting uranium carbide-zirconium carbide to this particular geometry.

The Dumbo project was canceled in 1959. Figure 6 is an excerpt from the progress report that described the cancellation. Basically what it says is we didn't see a heck of a lot of advantages as compared to the axial flow system. We thought it was going to be very complicated, tough engineering problem to develop the folded flow reactor. We had to put our resources either one place or the other and we chose to put them into the axial flow carbon-based systems.

Let me add as a historical footnote, that the small engineering design team, some three of us, who were working on engineering the Dumbo system, then went to work on other geometries, first on axial flow tungsten UO_2 systems and then began looking at new fuel geometries for carbon-based systems. By 1960, we had defined the parameters for the 19-hole fuel element was that the basis for the rest of the nuclear rocket program.

Let me now suggest some reasons why one might want to go to a Dumbo type system, which I will define as a folded flow washer type fuel system. This is a curve (Figure 7) Gerry Farbman showed you earlier. My version has bands on it rather than single lines. It also has the word on the right that I would ask you to look at very carefully: it says "preliminary" in talking about the possibilities for carbide fuel. But there is a lot of space between the predicted temperature capability of carbide fuel and that of composite and graphite fuel. That space I think forms the carrot that's involved in going to carbide fuel. However, there is also a stick, which has to do with thermal stress and consequently with power density that you can get from a carbide system. These limitations becomes important as the composite fuel fraction of UC-ZrC is increased, and as you go to 100 percent UC-ZrC, the thermal stress resistance decreases further and further.

There is also quite a problem in fabricating uranium carbide-zirconium carbide. Our

answer to that back in 1970 to 1972 was to use this particular fuel element (Figure 8), a single hole fuel element as opposed to a 19 hole fuel element for a couple of reasons. First of all it makes it smaller just from a fabrication point of view; it is about 1/12th the size of a 19-hole fuel element. Also it enables reducing the total thermal stress by reducing the element to one flow passage, and one set of fuel meat to go with that congruent passage rather than having several.

We did test a few of these carbide elements in the Nuclear Furnace. Two cells in the Nuclear Furnace held carbide elements; they fragmented rather badly under the power density of the Nuclear Furnace. However, it isn't clear that the fragmenting is a show-stopper.

One reason we worried about thermal stress for the graphite and composite elements is that any thermal stress fracture was a new path for corrosion. With the carbide fuel that's not so much a worry because the carbide fuel has an intensive resistance to corrosion. On the other hand, if the fractures in the fuel elements disturb the flow geometry, there may be real problems. That becomes potentially damaging to the entire core by changing the flow patterns in the core. Certain parts of the core are going to get cooler and certain parts are going to get hotter. You are either going to have to shut down (if you know this is happening through instrumentation readings), or if you don't know it's happening, you are probably going to melt out some parts of the core.

In considering the possible geometries for using uranium carbide-zirconium carbide we can include using it in a folded flow geometry as a washer. I have listed here just a few ideas (Figure 9) about what the fuel elements might look like. These are certainly nothing definitive, because at the time we were working on this before, we were looking at a cermet system, which has different properties. But you can think of a lot of ways that such a fuel might be defined. It's going to depend on interactions between the fabrication and design issues that come up, so that one can choose something that will work in both respects.

I put together a comparison for a 1500 megawatt, that is, a 75 K thrust reactor of some for the characteristics of a carbide Dumbo system and a couple of other systems (Figure 10); one a Rover fuel and the other a particle bed fuel. The assumptions that I made are listed at the bottom. I don't claim any great precision for these numbers; I think they reflect the assumptions that were made. But they give you some idea of the kind of characteristics that will be typical for these fuel geometries.

Based on the assumptions, fuel volume is different because we assume higher power density for the Advanced Dumbo and for the particle bed. On the other hand, the surface area, the heat transfer surface area, is increasing to the right in the figure because the surface-to-volume area of the fuel is increasing as we go to the right. Also, there is some variation in the flow area in the system; the flow area per unit volume of fuel is increasing. It doesn't necessarily always increase, because the volume of fuel

depends on the power density assumptions. If you believe, as I do, that the temperature/lifetime performance of a nuclear rocket engine is limited by mass loss from the fuel, not from an absolute temperature limit (but from mass loss either associated with corrosion or with evaporation of the various components), you might conclude that there could be an optimum fuel surface-to-volume ratio. This would be one that gives you the closest match between maximum temperature of the fuel and the exit gas temperature, but that limits the surface area that is exposed to corrosion because, as far as we know, total corrosion rates depend on surface area.

The corrosion can be characterized as a loss rate per unit surface area, and of course, this may depend on the surface temperature or the interior temperature of the fuel at a given location. I don't assert that that's true; I just say that it's a possibility that we need to look at in optimizing the design for the UC-ZrC system.

So the characteristics of the Advanced Dumbo (Figure 11) are that it offers an alternative fuel geometry. By having a higher surface to volume ratio of the fuel, it offers reduced thermal stress, as other people have suggested for this kind of geometry. I say it eases fuel fabrication for the UC-ZrC system with a question mark, because I'm not sure that it does. Compared to a particle bed system, it has a defined fuel passage; that is, once the coolant gets into the fuel it has only one place to go. And also compared to particle bed system the fuel is radially self-supporting.

I am a little amused that here I am saying that the fuel supporting itself is an advantage and other people are saying the fuel not supporting itself is an advantage, and I don't know which one of us is going to turn out to be correct.

The Advanced Dumbo system also has certain key design issues (Figure 12); I use the word issue to mean problem. Flow balancing has been talked about before, Dumbo is going to have the same need for an orificing system at the inlet of the fuel that any other fuel system or any other fuel geometry does. Folded flow systems, I think, have a considerable amount of engineering complexity compared to axial flow systems. Fuel fabricability in this particular geometry is an issue. As to thermal stress, I'm not sure that this geometry generally solves the thermal stress problem. And then axial support, particularly at the hot end, is going to be a problem, if indeed we are to be able to get a very, very high temperature propellant out of this system. These problems, of course, are shared to various degrees by similar concepts.

I mentioned earlier that there was another historical footnote, after the end of the nuclear rocket program. There was a rather bitter article in the December 1975 Analog science fiction magazine, in an article called "Atomic Rockets." It pointed out how stupid and conservative the administrators and engineers in the NERVA program had been for refusing to take the Dumbo system as the route to develop and said our lack of imagination had led to the termination of the nuclear rocket program. This article is one of my prize possessions, and while I would be glad to let you look through it please

leave it when you do. By the way, I don't mean to imply that I agree with any part of the article.

MR. ZUBRIN: As I recall, the original Dumbo had some very exotic microdynamics of the propellant going to plates and so forth, and they maintain the laminar flow --

MR. KIRK: The velocity was slow because you have a very, very high flow area compared to an axial flow system. By going folded flow you multiply the flow area by a fairly large factor.

MR. ZUBRIN: You are also in the laminar flow regime.

MR. KIRK: I don't know. It doesn't matter a heck of a lot to me whether it's laminar flow or turbulent flow. I am always going to have to have metering in the front end in order to get the right amount of fluid into the right passages.

BIBLIOGRAPHY

Bill Kirk

Dumbo

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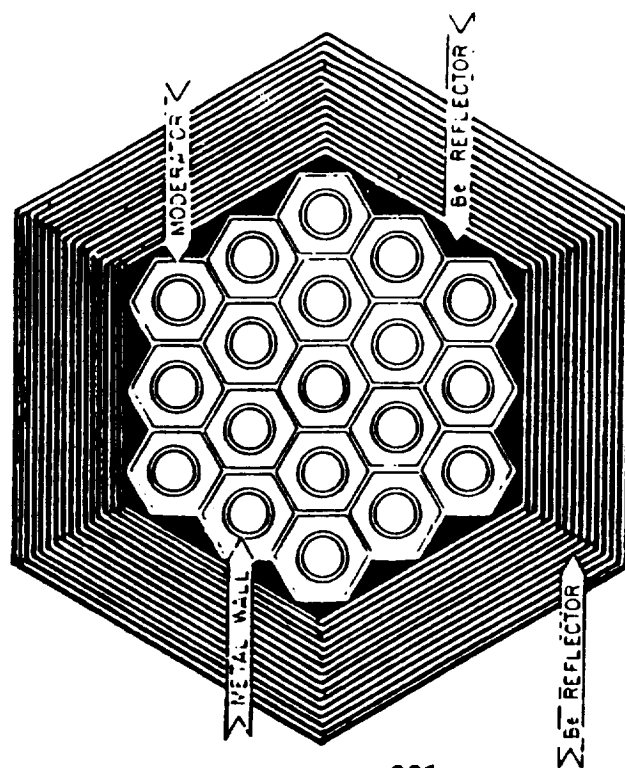


FIGURE 9-8
MODEL C DUMBO

SCALE 0 10 20 30
cm.

295

Figure 2

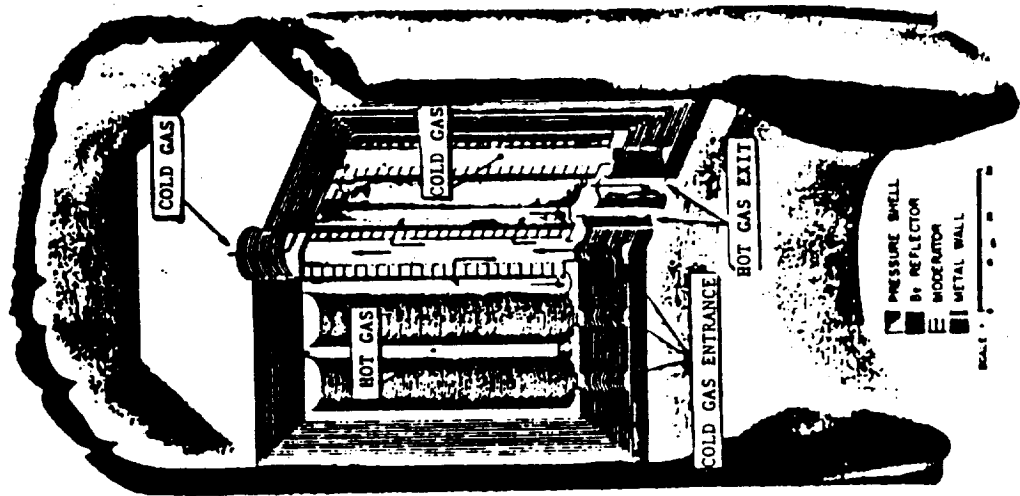
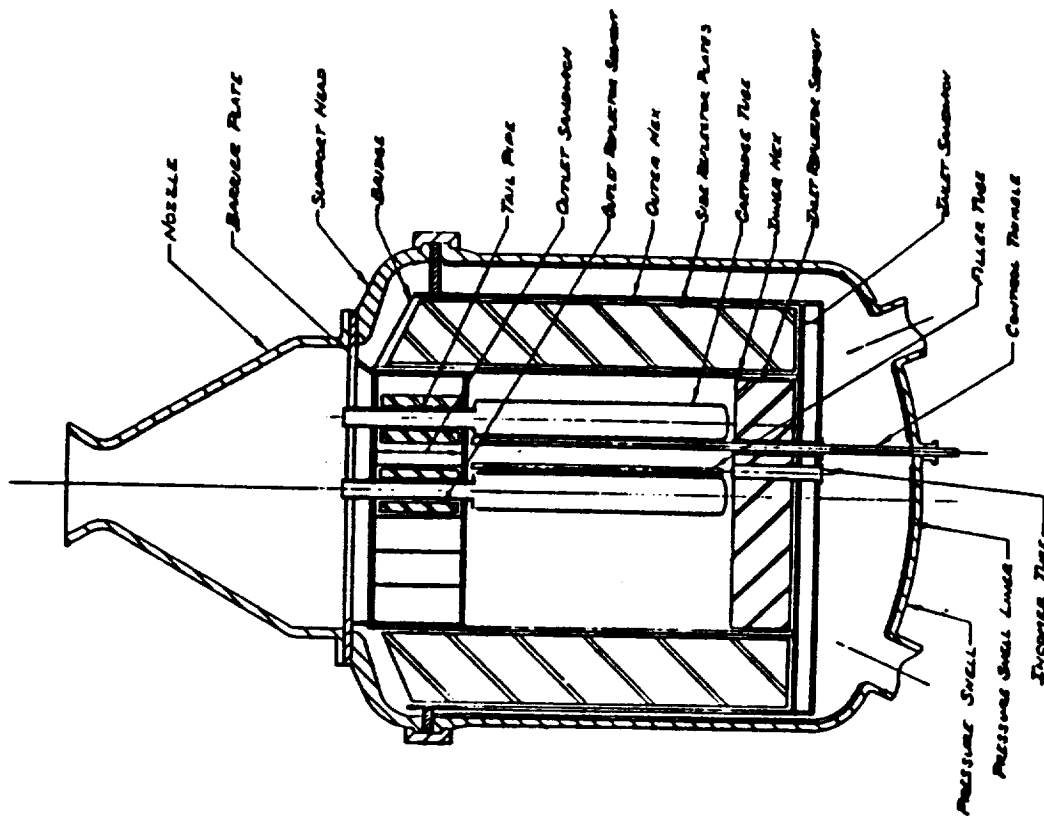


Figure 1

Typical Dumbo reactor



Nomenclature of Components of Dumbo-A

Figure 3

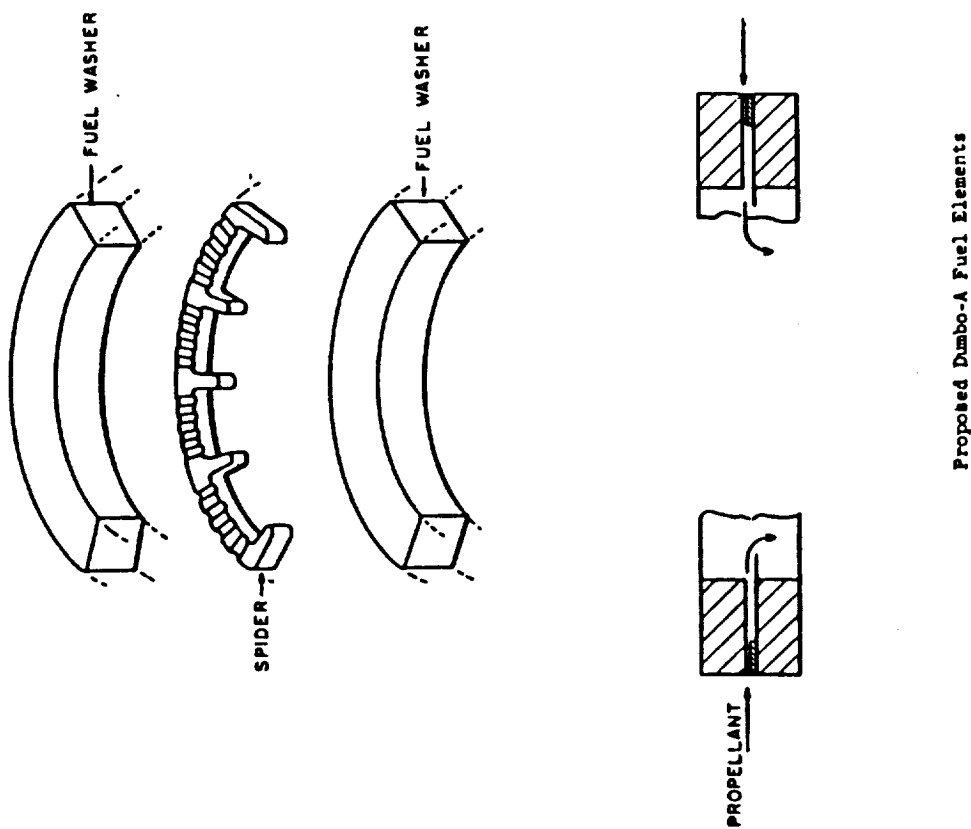


Figure 4

DUMBO

General Status

After reviewing the current status of the Dumbo (Molybdenum) reactor, the decision has been made to cancel the project. The two major factors which prompted this decision were (a) a recognition that the Dumbo design as it now exists does not offer any appreciable advantages in terms of performance or light weight over KIWI designs, and (B) the complexity of the design and the need for many precision parts, coupled with the difficulty of making meaningful component tests, leads to the conclusion that the development of a successful reactor would be a long and arduous task. It should be noted that the foregoing remarks refer in particular to a Mo-UO₂ fuel system. There is a possibility that with tungsten in place of molybdenum higher temperatures may be achieved than in graphite reactors. Consequently, an evaluation of tungsten-based fuel elements, in terms of their high-temperature capability, will be continued.

CHAPTER 4
QUARTERLY STATUS REPORT OF LASL
ROVER PROGRAM FOR PERIOD ENDING
SEPTEMBER 20, 1959

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DUMBO

KEY CHARACTERISTICS

- FOLDED FLOW
- FUEL WASHERS
- LARGE FLOW AREA
- LARGE FUEL SURFACE AREA
- SMALL FUEL VOLUME
- HYDRIDE MODERATOR
- CERMET FUEL (1959)
- UC-ZrC FUEL (1990)

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Figure 5

Figure 6

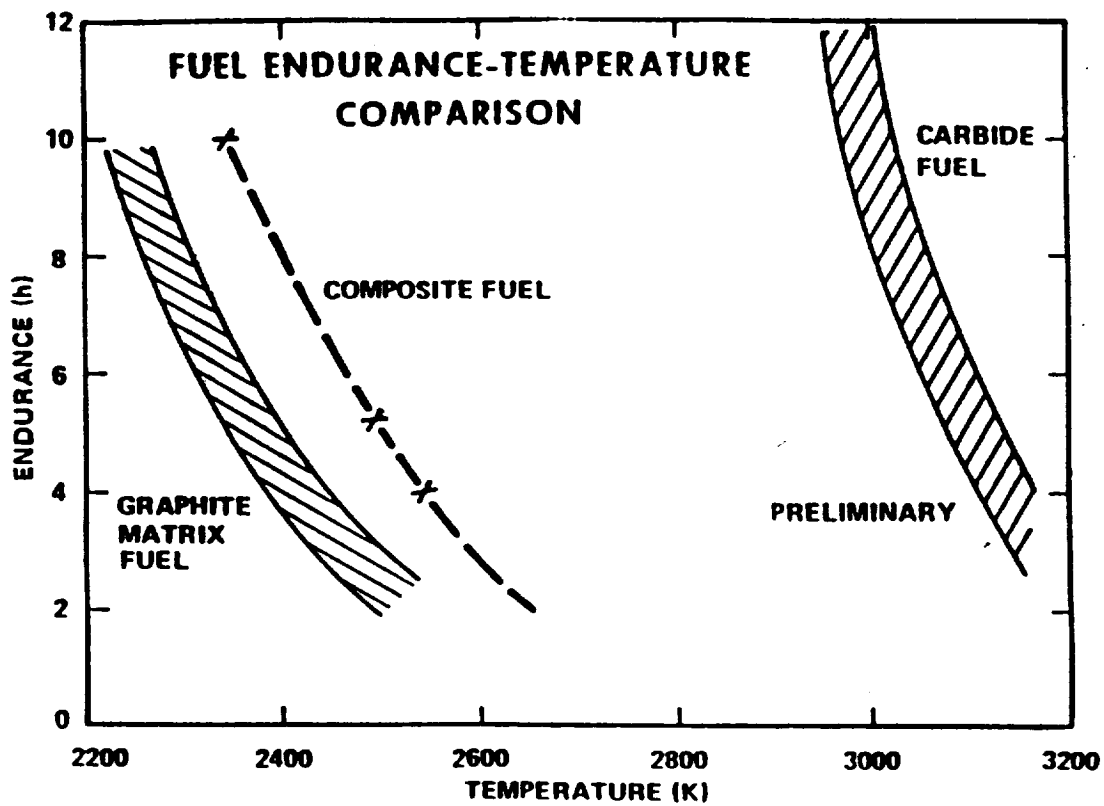
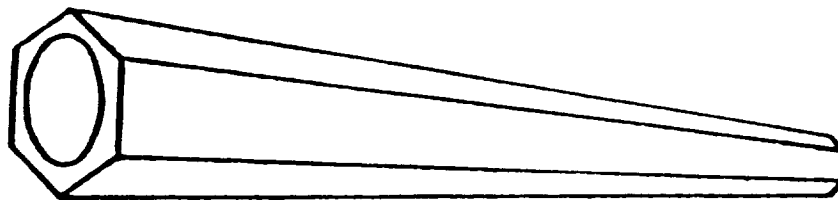


Figure 7



Full-length view of (U,Zr)C (carbide) fuel element. Length, 0.64 m; across flats, 5.5 mm; coolant-channel diameter, 3.2 mm; and carbon/metal atom ratio, 0.8 to 0.92.

Figure 8

ADVANCED DUMBO

POSSIBLE FUEL CONFIGURATIONS

1. FLAT FUELED WASHERS
ALTERNATING WITH GROOVED
UNLOADED WASHERS.
2. GROOVED FLAT FUEL
WASHERS
3. RADially SPLIT FLAT
WASHERS

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Figure 9

ESTIMATED FUEL PARAMETERS FOR A 1500 MW REACTOR

	ROVER FUEL*	ADVANCED** DUMBO	PARTICLE +
FUEL VOLUME, m^3	0.6	0.2	0.1
FUEL SURFACE AREA, cm^2	2.9×10^6	5.2×10^6	8.4×10^6
FUEL FLOW AREA, cm^2	1.4×10^3	4×10^4	1.6×10^4
FUEL SURFACE/ VOLUME RATIO, m^{-1}	480	2600	8400

*Based on 19-hole element with 1.1 MW/element (2500 MW/ m^3)

**Assumes 30-mil fuel and 10-mil flow passage, element $\bar{D} \approx 3$ in., fuel thickness ≈ 0.5 in. 7500 MW/ m^3

+Assumes 500 μ particles, 15,000 MW/ m^3 , 70% packing

Figure 10

ADVANCED DUMBO

FUNDAMENTAL DESIGN ISSUES

- **FLOW BALANCING**
- **ENGINEERING COMPLEXITY**
- **FUEL FABRICABILITY**
- **FUEL THERMAL STRESS**
- **AXIAL SUPPORT**

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ADVANCED DUMBO

OFFERS AN ALTERNATIVE FUEL GEOMETRY FOR UC-ZrC FUEL

- **REDUCES THERMAL STRESS**
- **EASES FUEL FABRICATION?**
- **DEFINED FUEL FLOW PASSAGE**
- **RADIALY SELF-SUPPORTING
FUEL**

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Figure 11

Figure 12